U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: FUEL TANK FLAMMABILITY MINIMIZATION	**Date:** DRAFT 01/12/00 **Initiated By:** ANM-112	**AC No:** 25.981-2X **Change:**

1. PURPOSE. This advisory circular provides information and guidance concerning compliance with the airworthiness standards for transport category airplanes pertaining to minimizing the formation or mitigation of hazards from flammable fuel air mixtures within fuel tanks. This guidance is applicable to transport category airplanes for which a new, amended, or supplemental type certificate is requested.

2. RELATED DOCUMENTS.

a. Federal Aviation Regulations. The applicable sections of 14 CFR part 25 that prescribe the design requirements for the substantiation and certification relating to prevention of ignition sources within the fuel tanks of transport category airplanes include:

§ 25.863	Flammable fluid fire protection
§ 25.901	Installation
§ 25.954	Fuel system lightning protection
§ 25.981	Fuel tank ignition prevention

b. Advisory Circulars (AC). The following FAA advisory circulars can be obtained from the U.S. Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785.

(1) AC 25-8 Auxiliary Fuel System Installations.

(2) AC 20-53A Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning.

(3) AC 25.981-1X Fuel Tank Ignition Source Prevention Guidelines.

c. Society of Automotive Engineers (SAE) Documents. The following documents can be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

(1) SAE AIR 5128 "Electrical Bonding of Aircraft Fuel System Plumbing Systems," (January 1997).

(2) SAE AIR 4170, "Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays," xx/xx/xx.

(3) SAE AIR 1903, "Aircraft Inerting Systems."

(4) SAE AIR 1662, "Minimization of Electrostatic Hazards in Aircraft Fuel Systems," (October 1984).

d. Military Specifications.

(1) MIL-B-83054, Baffle and Inerting Material, Aircraft Fuel Tank (March 1984). (Note: this reference provides an extensive list of military specifications relating to the use of polyurethane foam.)

e. Other.

(1) FAA Document DOT/FAA/AR-98/26, Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998. (A copy of this report can be obtained through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: **http://www.fire.tc.faa.gov**)

(2) Aviation Rulemaking Advisory Committee, Fuel Tank Harmonization Working Group, Final Report, July 1998 (a copy of this report may be obtained on line from the U.S. Department of Transportation (DOT) electronic dockets, Docket No. FAA-1998-4183, at the following web site address: http://dms.dot.gov).

(3) "Effects of Fuel Slosh and Vibration on the Flammability Hazards of Hydrocarbon Turbine Fuels Within Aircraft Fuel Tanks," Technical report AFAPL-TR-70-65 (November 1970), Edwin E. Ott. (Contact Airforce Aero Propulsion Laboratory , Airforce Systems Command, Wright-Patterson Air Force Base Ohio.)

(4) "Procedures for the Use of Fuels for Turbine Powered Aircraft," FAA Order 8110.34A, March 1980.

3. DEFINITIONS.

a. Flammable. Flammable, with respect to a fluid or gas, means susceptible to igniting readily or to exploding (14 CFR Part 1, Definitions).

b. Lean Fuel Vapor/Air Mixture. A fuel vapor mixture that has insufficient concentration of fuel molecules to support combustion.

c. Rich Fuel Vapor/Air Mixture. A fuel vapor mixture that contains a concentration of fuel molecules above that which will support combustion.

d. Fuel Air Ratio. The ratio of the weight of fuel vapor to the weight of air in the ullage.

e. Flammability Range. The pressure (i.e., altitude)/temperature domain where the fuel vapor/air mixture is flammable. This domain is dependent on the type of fuel used.

f. Lower Flammability Limit. The lower flammability limit (LFL) defines the temperature at a specific altitude below which the fuel vapor/air mixture is too lean to ignite. For the purpose of this AC, the lower flammability limit is considered to be equal to 16°F below the fuel flash point (FP), as determined by the American Society for Testing and Materials standard, D56-98a, "Standard Test Method for Flash Point by Tag Closed Tester," and corrected for altitude by -1°F per 850 ft. altitude increase from sea level up to 45,000 ft.

g. Upper Flammability Limit. The upper flammability limit (UFL) defines the temperature at a specific altitude, above which the fuel vapor/air mixture is too rich to ignite. For the purpose of this AC, the upper flammability limit is considered to be equal to the fuel flash point +60°F, and corrected for altitude by -1°F per 650 ft. altitude increase from sea level up to 45,000 ft.

Note: This simple approach to define LFL and UFL has been taken in lieu of any conclusive data on flammability versus ignition energy versus altitude, and the lack of any data on the probability of an ignition source of a given energy level being present in a fuel tank. Figure 1 of Appendix 2 to this AC shows the flammability limits as a function of altitude and liquid fuel temperature relative to flash point based upon available information. (FAA Document DOT/FAA/AR-98/26 provides further information on this subject.)

h. Fuel Types. Different fuels are approved for use in turbine powered airplanes. The most widely used fuel types are JET-A/JET-A1 and JET-B (JP-4), per ASTM Specification D1655-99, "Standard Specification for Aviation Turbine Fuels." The approved fuel types for a given airplane type are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties, those directly related to flammability are flash point and distillation characteristics. Property differences can occur in a given fuel type as a result of variations in the source crude oil properties and the refining process used to produce the fuel.

i. Ullage, or Ullage Space. The volume within the tank not occupied by liquid fuel.

j. Fuel Tank. An aircraft volume containing fuel. Tanks contain both liquid fuel and, in the vapor space or ullage space, a fuel vapor/air mixture, with some water vapor, depending on the relative humidity in the tank.

k. Unheated Wing Tank. A conventional aluminum structure, integral tank of a subsonic transport wing, with minimum heat input from aircraft systems or other fuel tanks that are heated.

l. Operational Time. The time from the start of preparing the airplane for flight, (turning on the APU/ground power, starting environmental control systems etc.,), through the actual flight and landing and the time to disembark any payload/passengers and crew.

4. BACKGROUND.

a. Amendment 25-11 to part 25 introduced the requirements of § 25.981 pertaining to limiting temperatures in fuel tanks so as to prevent ignition of fuel vapors in the fuel tanks from hot surfaces. Advisory Circular 25.981-1A, published in 1972, provided guidance that included failure modes that should be considered when determining compliance with the fuel tank temperature requirements defined in § 25.981.

b. Other sections of part 25 require prevention of ignition sources from lightning (§ 25.954) and from failures in the fuel tank system (e.g., §§ 25.901 & 25.1309). Applicants have been required by §§ 25.901 and 25.1309 to evaluate the fuel tank system and show that "no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane.…" However, service history has shown that ignition sources have developed in airplane fuel tanks due to external ignition sources, and internal ignition sources resulting from unforeseen failure modes or factors that were not considered at the time of original certification of the airplane.

c. Section 25.981, as amended by Amendment 25-XX [insert amdt. number when SFAR issued], was adopted to provide improved standards for preventing ignition sources within fuel tanks and also to minimize the exposure to operation of transport airplanes with flammable vapors in the fuel tanks. Under Amendment 25-XX, the title of § 25.981 was renamed "Fuel tank ignition prevention," and paragraphs (a) and (b) were revised to address the prevention of ignition sources within the fuel tanks. Guidance regarding these paragraphs is provided in AC 25.981-1X, Fuel Tank Ignition Source Prevention Guidelines. Amendment 25-XX also added a new paragraph (c), which requires minimization of the formation of flammable vapors in the fuel tanks, or mitigation of any hazards if ignition does occur. Section 25.981(c) is intended to promote design practices that reduce exposure to operation with flammable vapors in transport airplane fuel tanks to the lowest practical level.

d. The changes to § 25.981 adopted by Amendment 25-XX are not intended to require prevention of the development of flammable vapors in fuel tanks, because methods that could completely prevent the development of flammable vapors in fuel tanks, such as fuel tank inerting, have not currently been shown to be practical. Rather, it is intended to preclude the use of design methods that result in a relatively high likelihood that flammable vapors will develop in fuel tanks when other practical design methods are available that can reduce the likelihood of such development. For example, the regulation does not prohibit installation of fuel tanks in the cargo compartment, placing heat exchangers in fuel tanks, or locating a fuel tank in the center wing. The regulation does, however, require that practical means, such as transferring heat from the fuel tank (e.g., use of ventilation or cooling air), be incorporated into the airplane design if heat sources were placed in or near the fuel tanks that significantly increased the formation of flammable fuel vapors in the tank, or if the tank is located in an area of the airplane where little or no cooling occurs. The intent of the regulation is to require that the exposure to formation or presence of flammable vapors is equivalent to that of an unheated wing tank in the transport airplane being evaluated. This may require incorporating design features to minimize formation of flammable vapors, or means to mitigate the hazards assuming that ignition does occur in fuel tanks, such as those located in the center wing box, horizontal stabilizer, cargo compartment, or other pressurized areas of the airplane.

e. This AC describes acceptable methods for minimizing the exposure of fuel tanks to flammable vapors, and discusses the installation of fire suppressing polyurethane foam as an explosion suppression means that may be used in lieu of reducing flammability exposure.

Applicable Proposed Regulations (shown for reviewer reference only, to be deleted in final version of AC):

(c) The fuel tank installation must include:

(1) Means to minimize the development of flammable vapors in the fuel tanks, or

(2) Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing.

5. DEMONSTRATING COMPLIANCE WITH THE REGULATIONS.
Section 25.981(c) provides two options for addressing the hazards associated with fuel tank flammability: minimizing fuel tank flammability, and mitigating the hazards if ignition of the fuel vapors occurs.

a. Minimizing Fuel Tank Flammability. Generally, the critical considerations in minimizing the exposure to operation with flammable mixtures in the tank include the fuel type, fuel temperature, and any design feature that increases the potential for fuel mists to be created. Design practices that reduce the overall flammability risk are described below. Airplane designs submitted for FAA evaluation will be evaluated against these practices. As the intent of the regulation is to limit the exposure of fuel tanks to flammable fuel vapor/air mixtures to a small amount of the operational time for that airplane type, practical design precautions, discussed within this AC, should be taken.

(1) Misting and sloshing. The flammability of fuel vapors in a fuel tank can be dramatically influenced by agitation, sloshing, or misting of fuel, which results in a higher concentration of fuel molecules in the ullage space. Design practices that reduce the potential for fuel agitation, sloshing, and misting should be incorporated into the design so that flammability is minimized. Examples of proven design practices include installation of sufficient baffling in the tanks to reduce sloshing, returning any fuel used to cool fuel pumps to the bottom of the tank, introducing fuel during refueling at the bottom of the fuel tank through low velocity nozzles, etc. Section 6 of SAE Document AIR 1662 describes recommended design practices for minimizing hazards associated with electrostatic charging in fuel tanks. Several of these practices relate to minimizing the formation of flammable vapors, including:

(a) Introducing fuel at low velocity near the bottom of fuel tanks, directing it to flow on a grounded conducting surface;

(b) Using a balanced distribution system to insure that all fuel tank bays are filled to equal levels to assist in reducing fuel velocity (this maximizes relaxation time and minimizes mist formation); and

(c) Using special precautions (reference paragraph 2e(4) of this AC) when switching from low vapor to high vapor pressure fuels. During “switch” loading, the fuel/air ratio in the ullage is almost certain to pass through the point of minimum ignition energy. These practices greatly reduce the presence of fuel mist that will broaden the flammability range of the fuel at the lean end and cause flammable vapors at temperatures well below the flash point.

(2) Fuel Types. The flash point of the fuels proposed for each application should be carefully evaluated. Use of any low flash point fuels, such as JP-4 (and other fuels such as Russian or Chinese fuels) must be analyzed if proposed for use as an approved fuel, as continuous use of JP-4 type fuels on a typical transport airplane may significantly increase operational exposure to flammable vapors; therefore, other minimization means, such as inerting, may be required to mitigate the exposure created by continuous use of such fuels. Applicants may propose limited use of such fuels for ferry flights or for limited passenger-carrying operations, similar to operations under the Master Minimum Equipment List. Appropriate limitations may be placed in the Airplane Flight Manual to address this issue.

(3) Fuel Tank Temperature. On any one airplane type, the most effective methods for controlling fuel tank temperature may vary between different fuel tanks, according to their exposure to the risk. For instance, fuel tanks located in the wings of subsonic transport airplanes, with little or no heat input from airplane systems or from other adjacent fuel tanks , have been analyzed and shown to meet the intent of the regulation, whereas fuel tanks located within the fuselage contours require more design attention. For example, auxiliary fuel tanks

located in the cargo compartment or pressurized areas, tanks located in the center wing box, and horizontal stabilizer tanks may have less ability to reject heat to ambient air, both on the ground and in flight, and may be subject to heat sources from equipment located nearby in the fuselage such as the air conditioning packs that supply cool air to the cabin. For fuel tanks that, because of installation location and/or other factors, do not minimize the exposure to operation with flammable vapors, the additional design criteria of § 25.981(c) should be provided. The following are examples of design solutions that may be proposed:

(a) Managing Heat Transfer to the Fuel Tank. In general, heat sources should not be located near fuel tanks, and heating from other sources, such as hydraulic heat exchangers or rejection of heat from engine systems, should be minimized. The transfer of significant quantities of heat into fuel tanks under normal operating conditions should be prevented, unless other means are provided to achieve the desired goal of showing the tank flammability is equivalent to the unheated wing tanks. Locating heat-producing systems away from the tanks should be considered. If this is not a practical solution, controlling heat transfer to the fuel tank should be addressed. Possible technical solutions include the use of thermal insulation blankets, and/or providing ventilation or dedicated cooling to remove excess heat from areas adjacent to the tank.

(b) Cooling/Ventilation of Fuel Tanks. If the fuel tank is located in an area of the airplane where little or no cooling occurs, such as the center wing box, horizontal stabilizer, or auxiliary fuel tanks located in the cargo compartment, ventilation or dedicated cooling may also be an effective means of demonstrating compliance. The cooling/ventilation means should be effective under all operating conditions, including ground and flight operation, considered necessary to achieve the desired goal of showing the tank flammability is equivalent to the unheated wing tanks. Adequate cooling/ventilation may be provided for certain airplane types by means such as installation of an air gap in spaces adjacent to fuel tanks and utilizing a fan during ground operation, and the use of ram air inlets for in-flight operation to transfer heat from the tank. Other means (e.g., bleeding cool air from the ECS packs into the air gap) may also be effective at providing adequate cooling/ventilation of the tank.

Some auxiliary fuel tank installations have been designed to use cabin air pressure vented into the tank as a means to transfer fuel from the fuel tank. One means of maintaining a lean mixture may be venting air from the transfer system air source though the empty tank. The criteria/guidance provided in paragraph 5a(4), Fuel Tank Ullage Sweeping, should be considered if this approach is used.

(c) Acceptable Means of Determining the Flammability Exposure of a Given Tank. Fuel tank flammability is heavily influenced by the temperature of the fuel in the fuel tanks. Integral aluminum fuel tanks located in the wing, fueled with Jet A type fuel, operated on typical flight profiles, and not heated by airplane heat sources, have been shown to minimize the formation of flammable fuel vapors. Two methods of demonstrating equivalence to unheated wing tanks are discussed in Appendix 1 and Appendix 2 to this AC. The first is a simplified method based primarily on using flight test to show that the flammability exposure of the fuel tank is equivalent to an unheated wing fuel tank. Temperature measurements are made for the unheated wing fuel tank and the tank of interest during various flight missions to show that the subject tank temperature is equal to the wing fuel tank. The second method is based upon development of a validated fuel tank thermal model for both an unheated wing tank and the tank of interest, and an analysis of the airplane type fleet operation to show overall fleet exposure to flammability is equivalent to the unheated wing tank. In this case the fuel temperature of the tank of interest may not be equivalent to an unheated wing fuel tank under all conditions. Temperature control may be used to regulate the flammability so that overall flammability exposure is shown to be equivalent to the unheated wing fuel tank.

Any subsonic transport airplane with wing fuel tanks only that is designed in accordance with the design guidelines identified in paragraphs 5(a)(1), (2), and (3) of this AC would be considered to meet the intent of the rule without further evaluation. If the tank of interest is not shown to have equivalent exposure to the unheated wing tank, the applicant should consider alternative means to reduce flammability, or to mitigate the effect of an ignition in the tank, as described in the following paragraphs.

(4) Fuel Tank Ullage Sweeping. A positive ventilation system may be used to "sweep" the ullage of flammable fuel vapor/air mixtures at a rate that keeps the ullage lean in spite of a higher than desirable fuel temperature. This ventilation system may be used as needed to satisfy the requirement of the regulation, but should address any negative effects such as sweeping unburned hydrocarbons into the atmosphere. It should be demonstrated that the ullage sweeping system does not leave pockets of flammable fuel vapor-air mixtures within the tank.

(5) Fuel Tank Inerting. Fuel tank inerting is another way of reducing the flammability exposure within a given tank. The accepted level for tank inerting used by the military is to reduce the oxygen content of the tank ullage to less than 9% (SAE Document 1903, "Aircraft Inerting Systems," describes considerations for installation of inerting systems). The minimum oxygen concentration needed to prevent a catastrophic fuel tank rupture in commercial applications may vary by tank design; therefore, a 10% by volume oxygen concentration level is acceptable for transport airplane fuel tanks.

The applicant may show that inerting is only needed for certain missions or parts of a mission to bring the tank fuel vapor/air mixture average exposure down to an acceptable level. Inerting may be achieved by supplying inert gas from on-board storage bottles, holding either gas or liquid inerting agent, on board inert gas generation systems (OBIGGS), or from a ground storage system if the tank is inerted only on the ground. Evidence that the inerting system does not leave pockets of oxygen concentrations above the maximum level within the tank should be provided. The effect of oxygen evolving from the fuel during pressure reduction conditions, such as during climb, should be addressed. In addition, the applicant must substantiate that the added system meets the installation requirements of part 25 and does not decrease the overall safety of the airplane.

(6) Higher Flash Point Fuels. One method of minimizing the exposure to operation with flammable fuel vapors is to restrict the fuel type specified in the Airplane Flight Manual to higher flash point fuels (e.g., JP-5, 140 ºF flash point). This method, in combination with other means, may be effective at reducing the exposure. However, as discussed in the ARAC Fuel Tank Harmonization Working Group Report (reference paragraph e(2) of this AC), this approach is not considered to be practical at this time.

b. Acceptable Means to Mitigate the Effects of an Explosion.

(1) An alternative to satisfying the requirements of § 25.981(b) is to provide a means to protect a tank from structural and systems damage that could prevent continued safe flight and landing of the airplane. This alternative recognizes that an applicant may choose to accept a high flammability exposure in a given tank and to provide additional protection to extinguish or suppress an explosion in a tank if an ignition occurs.

(2) The use of appropriate foams to fill the fuel tank and thereby control the pressure rise following an ignition of the fuel vapor/air mixture has been demonstrated by the USAF and other military forces to be effective, and is in use on several airplane types. The applicant may use such a foam installation to satisfy the requirement of § 25.981(b). The foam type should be demonstrated to be effective in suppressing explosions to a level where structural and system damage is prevented. The applicant should:

(a) Provide data on the foam, including material, pore size, and intended method for installing the foam in the tank.

(b) Address the potential for, and the effects of, degradation of the foam, from any environmental effects and long term aging, on both the airplane and engine fuel systems.

(c) Address the effects of the foam installation on fuel system performance, including engine feed, venting, unusable fuel, sump capacity, expansion space capacity, fueling, and defueling, including the effect of the foam on electrostatic buildup in the tank.

(d) Address the effect of the foam installation on the airplane fuel system, as well as the APU and engine fuel systems, and develop maintenance procedures to ensure the foam is correctly installed, both initially and when reinstalled, if removed for access to the tank.

APPENDIX 1
METHOD I – SIMPLIFIED FLIGHT TEST METHOD

1. When a fuel tank is heated or cooled by a change in air temperature, the response of the fuel temperature is to increase or decrease, respectively, following an exponential decay law. On the ground, air temperature is considered to be ambient temperature at the airplane location, and in flight it will be the Total Air Temperature (TAT) experienced by the airplane. This

exponential trend is driven by the temperature difference between the Fuel and TAT, and the response of the mass of the fuel and tank, generally represented by the system time constant Tau.

2. The slope of the locus of the plot of the instantaneous rate of change of the fuel temperature versus the difference between the fuel temperature and TAT is -1/Tau. The plot of item 4 of Method I therefore represents a means to illustrate the responsiveness of the tank to a difference between fuel temperature and TAT. By analyzing a number of tank configurations and heating effects, it has been determined that a tank that falls into the acceptable zone of Figure 1 will have an acceptable flammability exposure and no further testing is required. Tanks with significant heat sources nearby will show a shift of the locus of the test results into the unacceptable region, as will a tank with a low heat transfer rate to the atmosphere. A sample of the analysis of a typical unheated wing tank is shown in Figures 2 through 5 of this appendix.

3. This method may be used on airplanes that have implemented means to minimize misting and sloshing of fuel, that use approved fuels with a flash point of 100°F or above, and that have AFM limitations to restrict the use of lower flash point fuels to emergency use only. This method only requires recording fuel tank temperature and total air temperature at regular intervals during several flights. The slope of the fuel temperature change against the difference between fuel temperature and total air temperature for each of the data sets recorded during the flight is then plotted. The resulting set of data points (locus) for an unheated tank is a near straight line, the slope of which provides the time constant for the thermal response of the tank. Since the flammability exposure is directly related to the time constant, an immediate assessment of flammability exposure can be made, without the need for any complex thermal analysis.

4. Analytical Considerations.

a. Testing has shown that when a fuel tank is heated and flammable fuel-air vapors have formed, cooling of the tank to temperatures below the flash point does not instantaneously produce a non flammable ullage space. It may take from 1 to 2 hours for fuel molecules in a vapor space to condense and bring the vapor space into a non-flammable state. This phenomenon is referred to in this AC as lag time.

b. The rate of condensing the fuel molecules from vapor space is greatly increased if the vapor space is exposed to a cold surface. Therefore, if tank temperature control is the method chosen to minimize exposure to flammable vapors, cooling of surfaces in the ullage of each bay of the fuel tank will likely be necessary. In addition, the tank temperature of some tanks that are heated or have limited capacity to transfer heat to the outside environment (e.g., center wing tanks or body fuel tanks) may need to be regulated on the ground such that the average overall flammability exposure will be equivalent to unheated wing tanks. For instance, some manufacturers have developed ventilation schemes that use regulated cabin air or forced ventilation of outside air to enhance cooling of the tank while the airplane is on the ground. Outside air has been used to obtain cooling in flight. While the temperature of the fuel in the center wing tanks may not be equivalent to that of the wing tanks under all operating conditions, the average exposure may be equivalent. For example, during hot day conditions (80 to 120°F) air from the cool environmental control system may be used to keep the tank of interest cooler than the wing tanks while the airplane is on the ground. During flight, the wing tank may cool at a faster rate, but due to the difference in initial temperature and the effects of lag time in condensing of the fuel from the tank ullage space, the overall exposure for the tank of interest may be lower or equivalent to the wing tanks.

5. Compliance Testing. Testing should include ground and flight conditions with variable fuel quantities, and any heat transfer from airplane generated sources to the fuel tank at the critical conditions. The thermal characteristics should be determined independently for critical areas within each tank. Baffling incorporated into most fuel tanks results in segmented volumes that may significantly affect heat transfer and, therefore, the flammability within the tank volume. If barriers or walls result in separate volumes within the tank and prevent mixing of the fuel and/or vapors in the tank, then each of these volumes should be evaluated independently to determine the worst case exposure for that tank.

a. Temperature Measurement. The location of test instrumentation should consider tank configuration and operational factors to determine which locations in the fuel tank require evaluation. The fuel temperature should be measured at critical locations in the tank for each of the critical fuel loading conditions. For example, if heat is transferred to the tank from a heat exchanger or any other source, the fuel temperature should be measured at the location in the tank where the highest temperature would occur, with the quantity of fuel measured from the minimum dispatchable to full level. This may require that tank surface temperature measurements are taken along with bulk fuel temperatures at multiple locations within the tank.

b. Test Conditions. The applicant should conduct a flight test (or equivalent validated analysis) to measure the change in temperature in each affected tank on the ground and in flight versus time. Two test flights are required, one representative of a short mission for the airplane and one representative of a long mission. The short mission should include at least 30 minutes of ground operation prior to flight, and the long mission at least 90 minutes of ground operation prior to flight. For the entire mission (i.e., from the start-up of airplane systems to completion of the flight), temperatures shall be recorded in the test tank(s) at locations to represent the bulk fuel temperature in each separate section of the test tank(s). For this discussion, total air temperature (TAT) is used to represent ambient temperature on the ground and TAT in flight. The fuel temperature and TAT shall be recorded at no less than 1-minute intervals.

6. Compliance Report. In order to show compliance using this method, the compliance report should include plots of the flight test data presented in the formats described below in paragraphs 6a through 6d for each flight, and the data comparison described in paragraph 6e should be included in the report.

a. Plot fuel temperature and TAT versus time.

b. Plot the difference between fuel temperature and TAT versus time.

c. Plot the instantaneous rate of fuel temperature change versus time.

d. Plot the rate of the fuel temperature change versus the difference between fuel temperature and TAT.

e. The plot described in paragraph 6d shall be compared to the "Acceptable/Not acceptable" criteria shown on Figure 1 below. If the entire locus of the data for both flights is in the acceptable region of Figure 1, that section of tank shall be deemed acceptable.

Rate of Fuel Temperature Change versus Delta temperature (fuel to TAT)

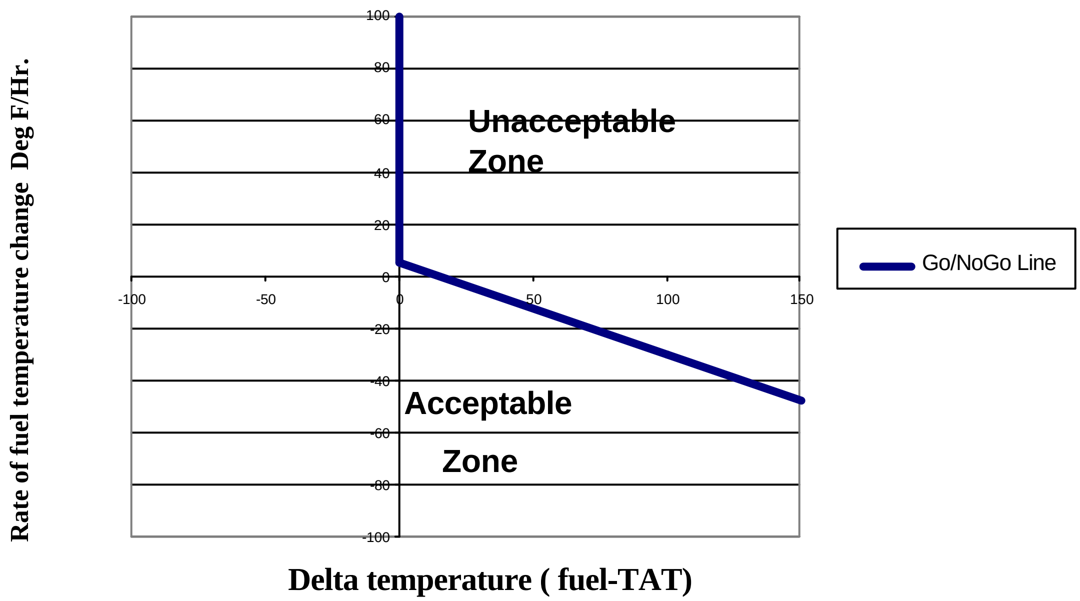

Figure 1. Rate of Fuel Temperature Change vs Delta Temperature (fuel to TAT)

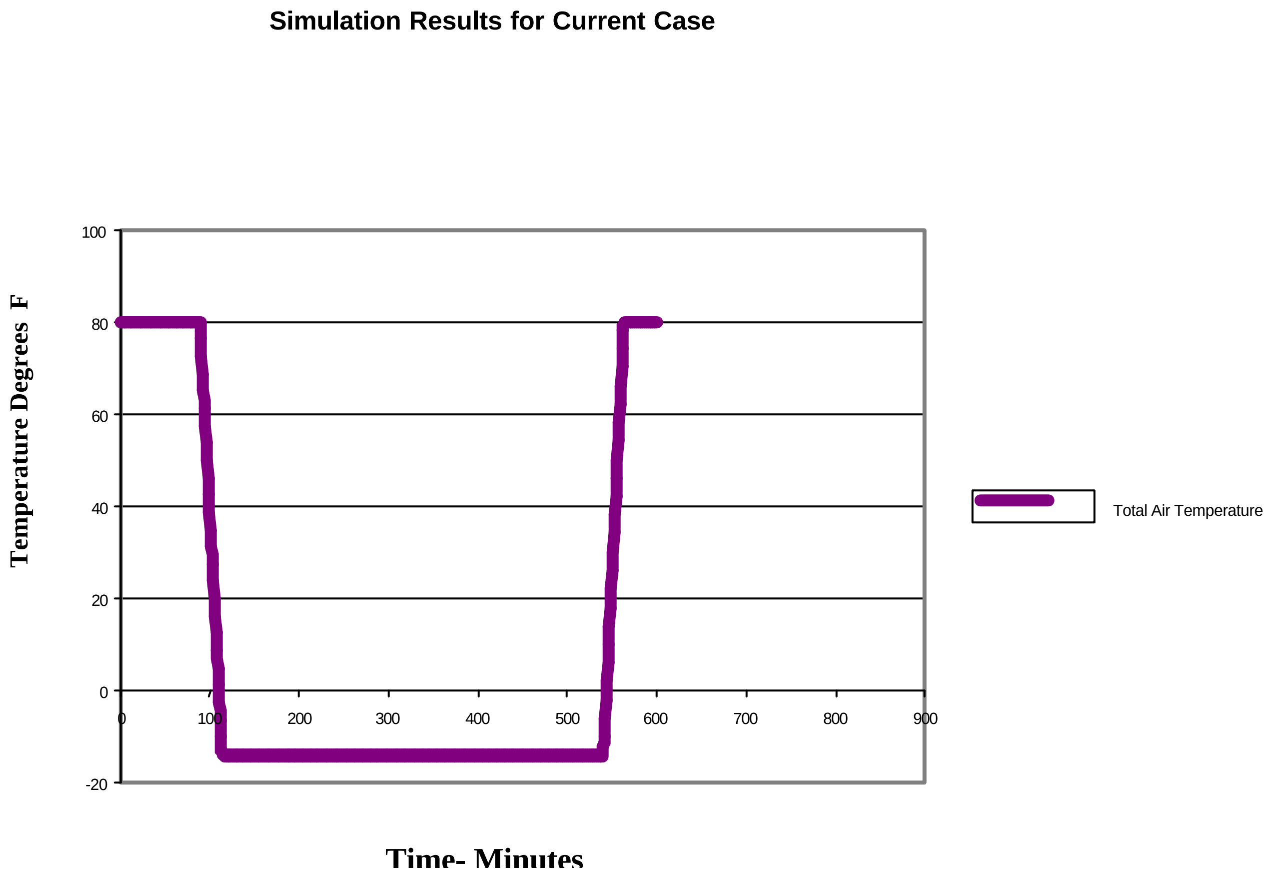

Figure 2. Example Plot of Total Air Temperature

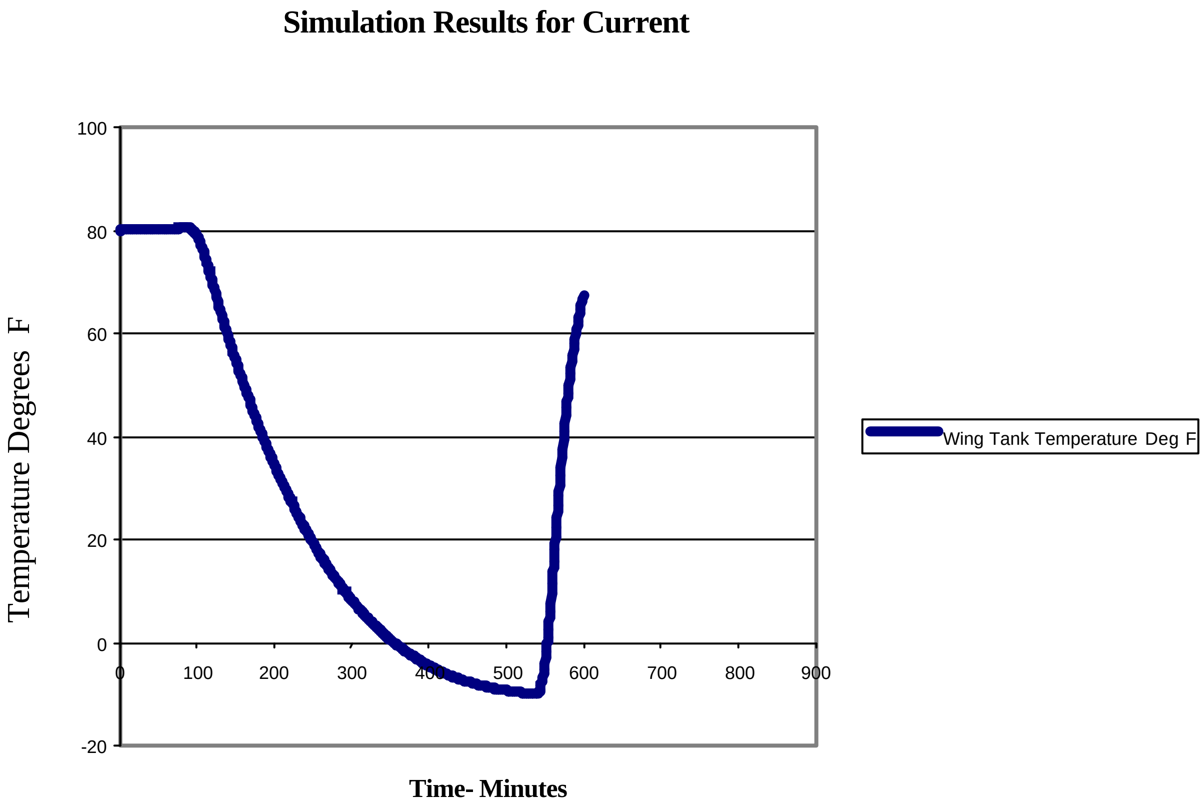

Figure 3. Example Plot of Total Air Temperature

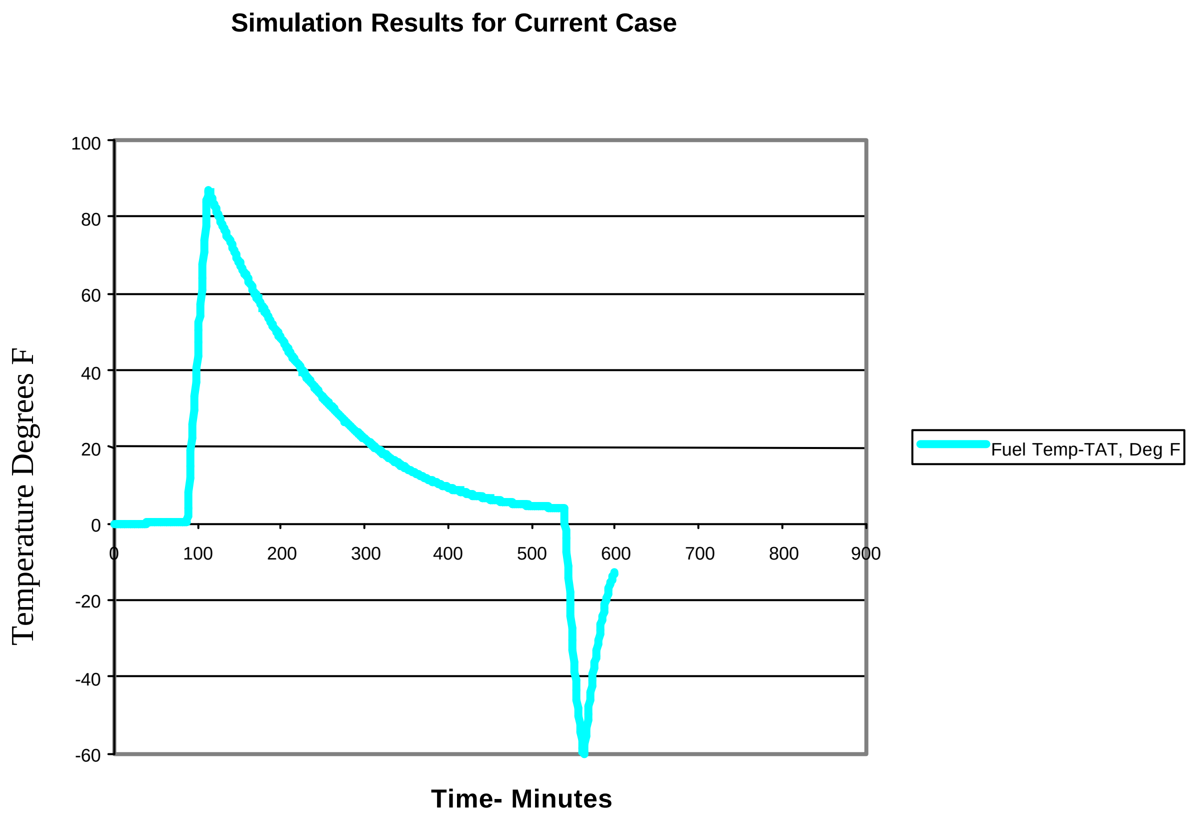

Figure 4. Example of Fuel Temperature Minus Total Air Temperature

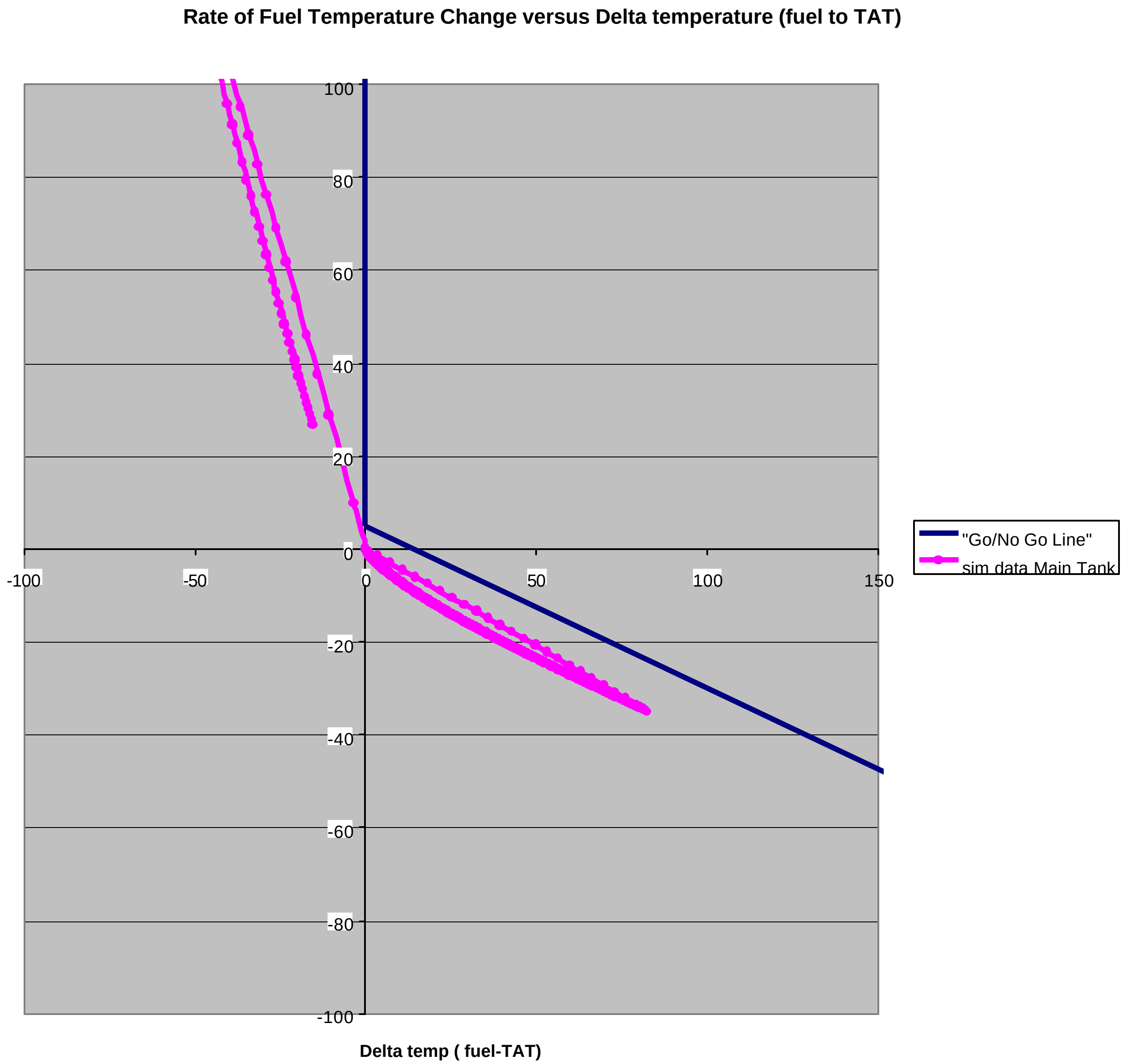

Figure 5. Example Plot of Wing Tank Temperature Change Versus Time

DRAFT - 01/12/00 AC 25.981-2X

APPENDIX 2

METHOD II – VALIDATED FUEL TANK MODEL

1. This analytical method is based upon predicting the average fleet exposure to operation with flammable fuel air vapors in the fuel tank. The average exposure is calculated for the specific fleet of airplanes of interest for which approval is sought. This method requires the development of a thermal model for the wing tanks and the tank of interest of a given airplane type, followed by a comparative analysis that considers factors that influence the fuel tank flammability. Factors that must be considered include fuel properties, mission length, fuel management, worldwide ambient temperature distribution, etc.

2. The presence of flammable vapors should be determined independently for each tank. Within each tank where barriers or walls prevent mixing of the fuel/air mixtures, separate volumes should be treated independently to determine the worst case exposure for that tank. The analysis should take into account all fuel types for which certification is sought, and the expected frequency of use for each fuel type.

3. To ensure that a consistent method and assumptions are used in this process, the following guidelines are provided.

a. A Monte-Carlo analysis of the tank in question should be conducted to show that the tank has a flammability exposure similar to unheated wing tanks over the expected range of operational conditions and fuel types. The Monte Carlo simulation, which randomly generates values for uncertain variables over and over, is used to simulate a process where the variables are random within defined distributions. The results of a large number of cases can then be used to approximate the results of the real world conditions. As this method is relatively complex, it is necessary to be very specific in the details of the analysis to avoid misinterpretation of the method and results. This method uses five key analyses techniques and databases:

(1) A validated computer simulation of the thermal behavior of the tank in question is developed to evaluate any likely flight profile.

(2) A statistical distribution of mission durations expected for the airplane model world wide is developed.

(3) A statistical distribution of ground and cruise temperatures likely to be experienced worldwide is used.

(4) A statistical distribution of likely fuel types, and properties of those fuels, expected to be seen worldwide is used.

(5) A definition of the conditions when the tank in question will be considered flammable is used.

b. Items (1) and (2) above should be created by the applicant. Rationale and validation data should be presented by the applicant to justify the items.

(1) Item 1 requires that an applicant create a computer model that can randomly select the following conditions: the ambient temperature at the airport of departure; the ambient temperature at cruise altitude; the flash point of the fuel loaded; and the mission duration. Using the randomly selected input conditions, the applicant can calculate the temperature of the fuel in the tank(s) in question along the mission profile. The applicant may also choose to calculate the Fuel Air Ratio (FAR) of the tank ullage along the mission profile. From this data, the applicant can calculate the time the tank(s) are flammable relative to the total mission duration. By repeating this process several hundreds of times, a fleet average flammability exposure, expressed as a percentage of the total operational time, can be calculated. The minimum number of cases to be run for this method should be 500 cases. The applicant should also conduct the same analysis for an unheated wing tank (as defined in paragraph 3, Definitions, of this AC) of the same model airplane as a reference. By comparing the reference unheated wing tank to the tank in question, the applicant can demonstrate that adequate provisions have been included in the design to minimize flammability exposure.

(2) The item 2 mission duration shall include ground operational time when the airplane systems (such as air-conditioning packs and other heat producing devices) are operating, unless limitations against use are placed on the airplane. The analyses shall assume that:

(a) For short flights (less than 25% of the airplane's maximum duration with a 75% payload), the preflight ground operational time shall be 30 minutes.

(b) For medium duration missions (between 25% and 60% of the airplane's maximum duration with a 75% payload), the preflight ground operational time shall be 45 minutes.

(c) For long duration missions (over 60% of the airplane's maximum duration with a 75% payload), the preflight ground operational time shall be 90 minutes.

c. Items 3, 4, and 5 are beyond the control of the applicant. To avoid confusion and provide standardization for all applicants, the following conditions are provided and should be used in the analyses to show compliance with the regulation, unless the applicant provides compelling information that would permit the use of alternatives.

(1) Item 3, Ground and Cruise Temperatures.

(a) The mean ground ambient temperature shall be assumed to be 59^{O}F, with a one sigma value of 30^{O}F.

(b) The mean tropopause temperature (high altitude, constant temperature) used in the analysis shall be -70^{O}F, with a one sigma value of 8^{O}F. Interpolation between the ground and tropopause temperatures shall be according to the following:

1 For ground ambient temperatures at or above 40^{O}F, the ground ambient temperature shall lapse at a rate of 3.57^{O}F per 1,000 ft., until the cruise temperature calculated for that flight is reached. Above that altitude, the temperature shall be constant.

2 For ground ambient temperatures colder than 40^{O}F, the temperature shall vary linearly with altitude to a temperature of 4.35^{O}F at 10,000 ft. and then lapse linearly at a rate of 3.57^{O}F per 1,000 ft. to intercept the cruise temperature calculated for that flight, and remain fixed at the cruise temperature above that altitude.

(2) Item 4, Fuel Types.

(a) Jet-A and Jet-A1 fuel shall be assumed to have a mean value of the flash point of 120^{O}F, and a one sigma variation of 8^{O}F.

(b) Jet-B/JP-4 fuels shall be assumed to be substantially limited in use (less than 0.5% of missions) or not approved for use on the airplane type under evaluation. Limits on the use of these fuels shall be controlled by the AFM, as discussed in paragraph 5(a)(2) of this AC. An applicant proposing to use Jet-B/JP-4 type fuels to a greater extent than the limited use defined above must define the expected usage, and assume the mean value of the flash point of Jet-B to be -20^{O}F, with a one sigma value of 5^{O}F.

(3) Item 5, Flammable Conditions.

(a) The upper and lower flammability limits shall be as defined in paragraphs 3(f) and (g) of this AC. An example of plotted flammability limits is shown in Figure 1.

(b) An applicant electing to include the effect of reduced fuel quantity on FAR in this method shall use the reduction correction shown in Figure 2.

(c) An applicant electing to use FAR as a measure of flammability in this method shall use the FAR limits versus altitude shown in Figure 3.

(d) The effect of the response time to build up or reduce FAR as pressure and temperature changes may be included in the analyses. The response rate varies with the volume of fuel in the tank, and should be established for the condition of interest (see paragraph 2(e)(1) of this AC). For example, an exponential response rate and the time constant, Tau, may be assumed as 90 minutes for increasing FAR and 60 minutes for reducing FAR for a full tank.

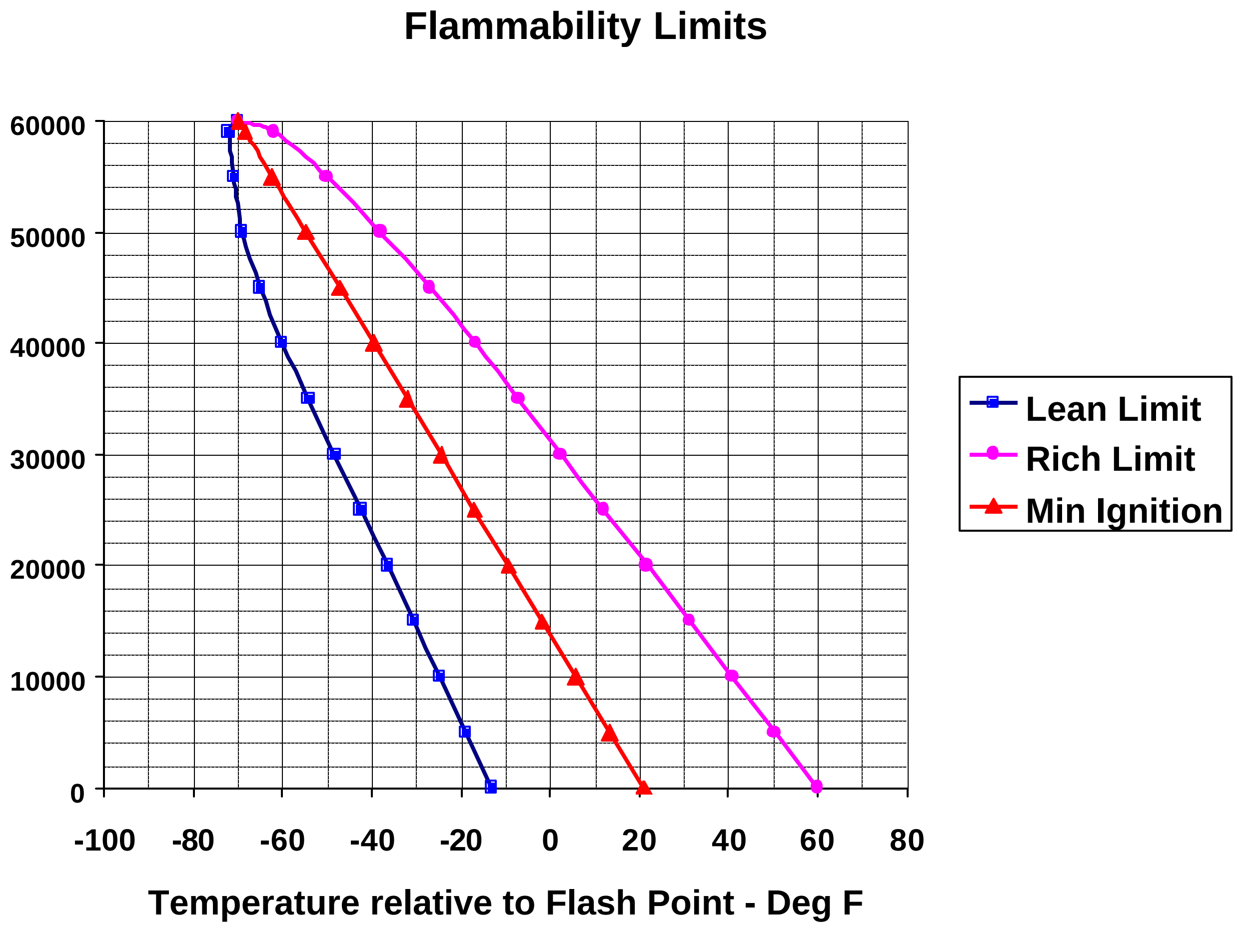

Figure 1: <u>Fuel Flammability Range as a Function of Altitude</u>

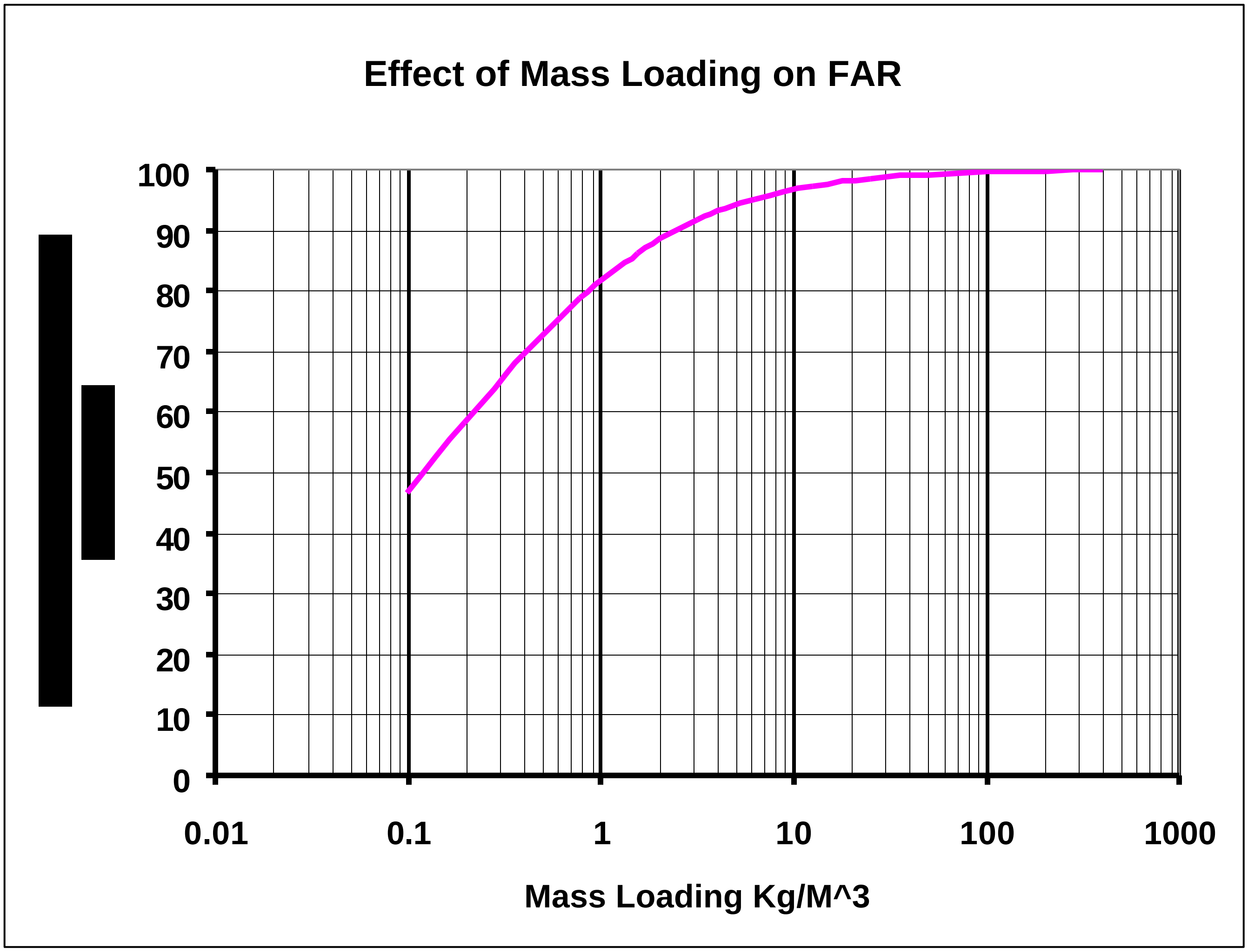

Figure 2: <u>Effects of Mass Loading on Fuel Air Ratio</u>

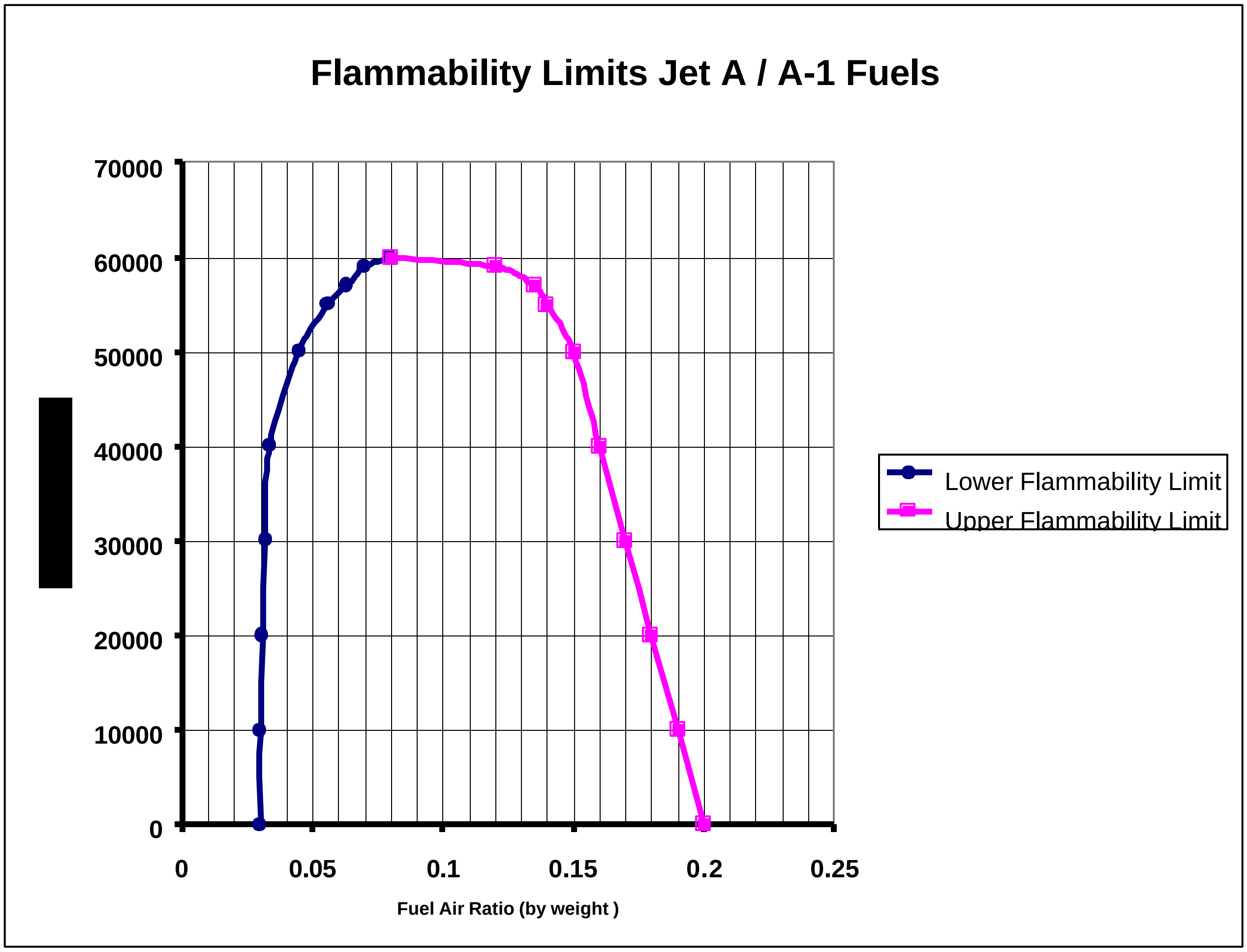

Figure 3: Fuel Vapor Flammability as a Function of Fuel Air Ratio

Note: The Flammability limits shown are based on available data and may be updated as research progresses.